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Title: Health Physics Considerations for Highly Radioactive Environments

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HEALTH PHYSICS CONSIDERATIONS FOR HIGHLY RADIOACTIVE ENVIRONMENTS

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SOME BASIC STUFF TO GET STARTED

- External radiation protection
  - Time, Distance, Shielding
    - $1/r^2$ for distance
    - Shielding – electron density for gammas, hydrogenous for neutrons (not an issue usually)
  - Sending the old guy
    - Teratogenic concerns
    - Cancer takes a while
    - But…younger folks may move faster and recover faster/be affected less
- Internal radiation protection
  - Keep it out of your body
    - Control it at the source
    - Minimize inhalation – respirators, and time
    - Minimize ingestion – PPE, hygiene, basic precautions
  - If it does get into you, we can minimize absorption, or increase excretion

MORE BASIC STUFF – UNITS

- Curies
  - 3.7 E10 DPS (3.7 E10 Bq)
  - Co-60 1.3 R/hr (11.34 mSv/hr) at 1m
  - Cs-137 321 mr/hr (2.82 mSv/hr) at 1m
  - Bqs
- Rem/Rad/Roentgen
- Regulatory vs practicable limits
  - 5 R (50 mSv) vs 25 R (250 mSv)
- Sv/Gy – 100 R

SCENARIO/ASSUMPTIONS

- Team is near a nuclear surface burst, well shielded from initial radiation
- Many of the statements include "it depends…" very few absolutes
- Radiation is only one part of the problems
- Adequate sealed food is available

NUCLEAR BLAST FUNDAMENTALS

- Yield is measured in kT
  - 1,000 tons of TNT-equivalent explosive force
  - Assuming 35 tons in semi-truck, 1kT = 28 semi trucks of TNT (>1/4 mile)
- Detonation is divided into 3 energy compartments*
  - Shock – 50%
  - Thermal – 35%
  - Radiation – 15%
    - Initial (within ~1min) 5%
    - Delayed (residual) 10% - not counted in yield calcs

* For a fission weapon w/HOB <40k feet. For thermonuclear weapons and other scenarios it changes.

ELECTROMAGNETIC PULSE (EMP)

- All explosions can produce electromagnetic fields
- Nuclear explosions produce significant EMP because of prompt radiation
  - Prompt gamma radiation interact and ionize nearby molecules, charge separation creates electric field pulse
  - Ground is a good shield and conductor, and strong magnetic fields will be generated for a mile or more
- Damage occurs to electronics and electrical equipment
  - RF deposited in components
  - RF generates voltage surge – especially on long conductors
  - Depends on duration of pulse, distance from deposition region, etc.
- Also Transient Radiation Effects (TREE) – from direct radiation exposure
  - Ionization
  - Direct damage to materials

PROMPT RADIATION

Gammas 500 yd, 2 kt, 10kR (100Sv)

- From fissions
- From fission fragments
- From neutron activation

- Shielded by dense material

Neutrons 500 yd, 2 kt, 12kR (120 SV)

- From fission

- Moderated by hydrogenous material

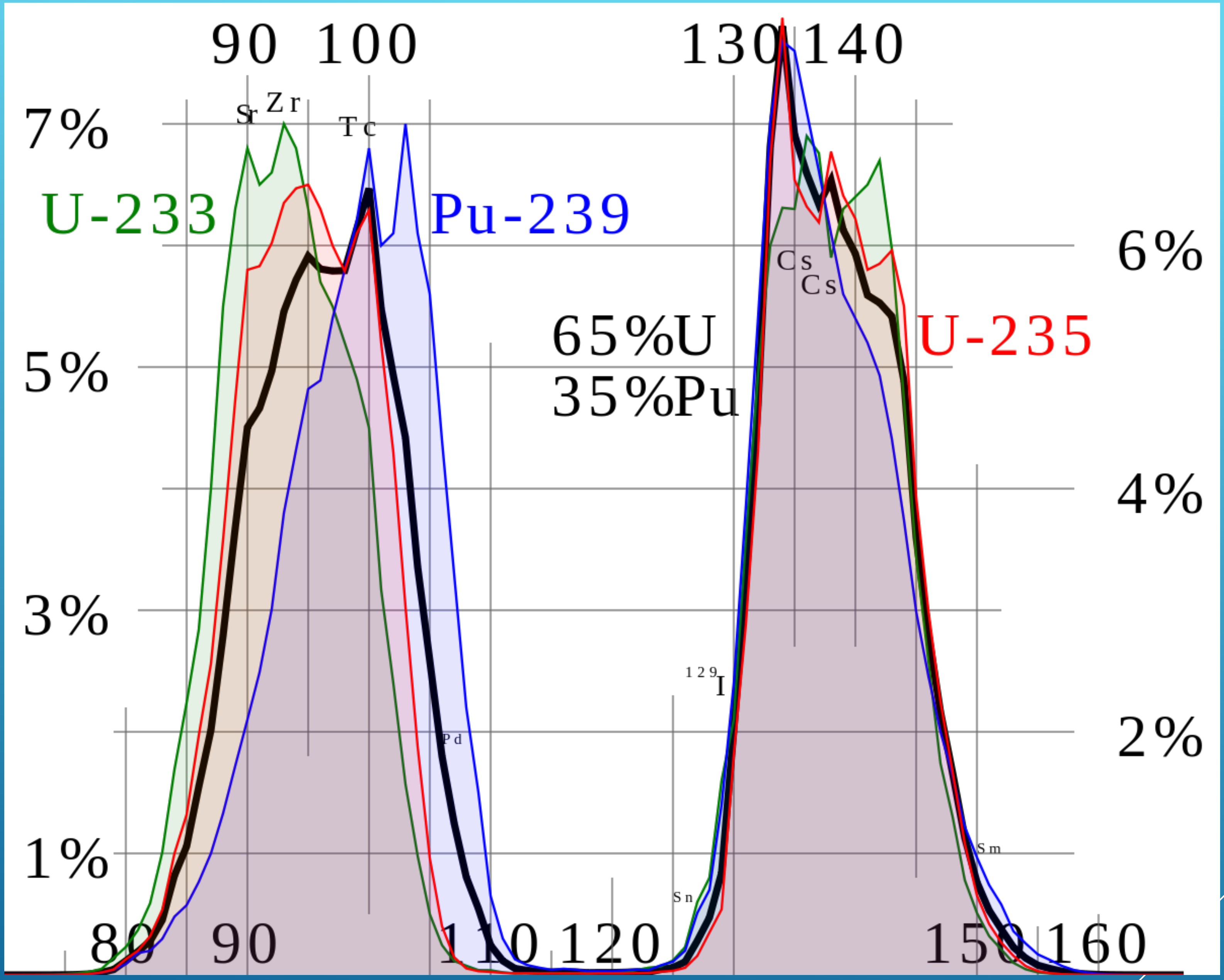
RESIDUAL RADIATION

- Fallout – materials that were not lofted
  - Large particles – resistant to resuspension or transport
  - Fission products
  - Activation of weapon, immediate surroundings
- Activation of materials in the vicinity of the burst by fission neutrons
- 3E23 fission product atoms/kt
- At 1 min 3E10 Ci (1.11 E21 Bq)
- 7/10 ROT – For every factor of 7 in time, dose rate decreases by 1/10
  - Surface roughness
  - Fractionation and speciation

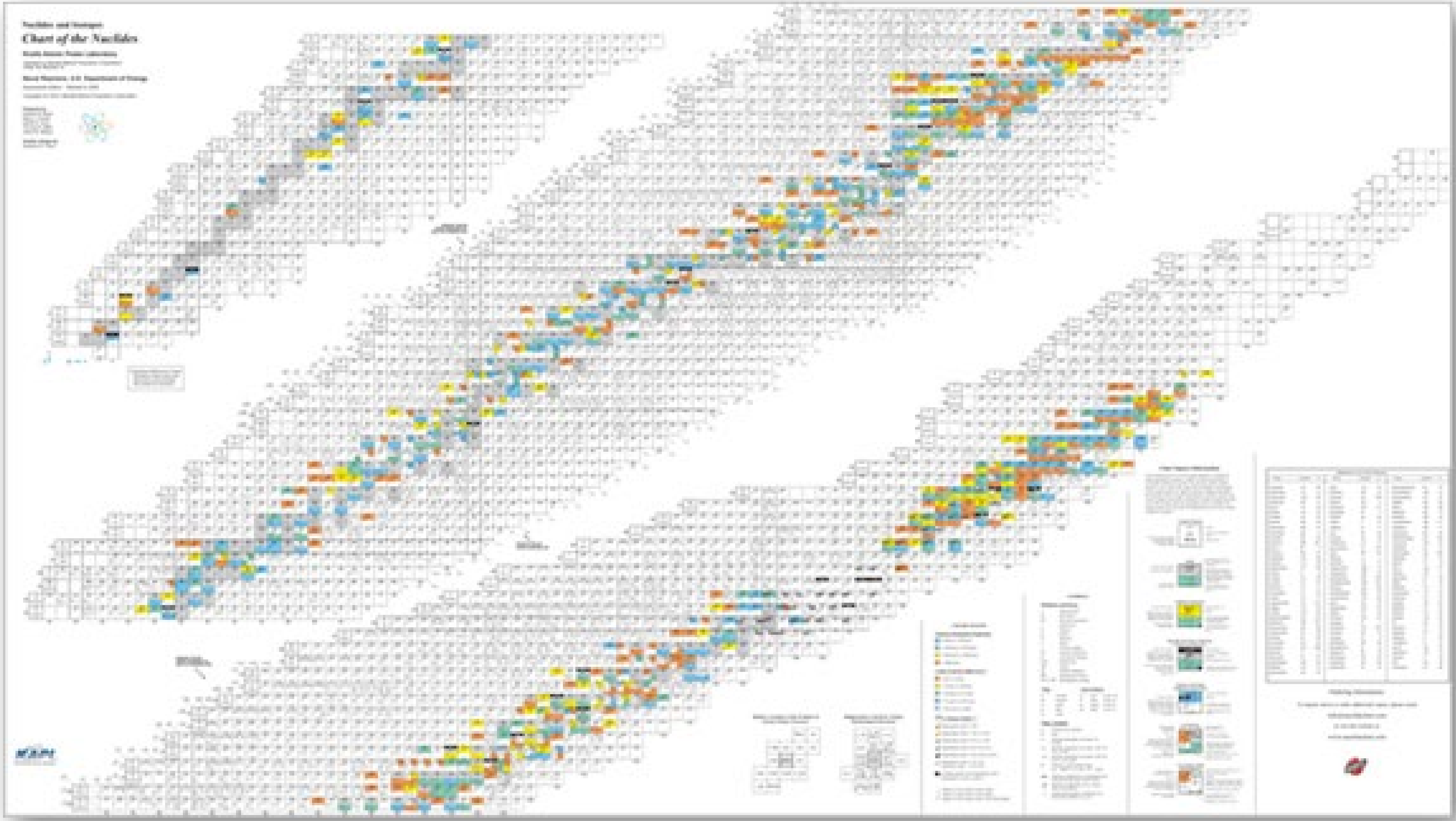
ISOTOPES IN FALLOUT

- 1 kt =~ 3E23 fission product atoms
- 10 tons =~ 3 E21 fission fragments
- At 1 minute ~ 3 E8 Ci (1.11E19 Bq) – does not account for activation products
- Many beta emitters, at 24 hrs a 2,000x reduction from 1min value
- More than 300 isotopes identified, but about 80 are formed
- I131 – 2% of FFs 1.6 E5 Ci (5.9 E15 Bq)/kt 10t = 1.6E3 Ci (5.9 E13 Bq)
- Sr90 & Sr89 3% of FFs 190 Ci (7E12 Bq)/kt and 3.8E4 Ci (1.4E15 Bq)/kt 10t = 2Ci (7.4 E10 Bq) & 380 Ci (1.4E13 Bq)
- Cs137 ~3.25% of FFs 200 Ci/kt 10t = 2 Ci (7.4 E10 Bq)

- Other isotopes – various physical and chemical states
  - Right place, right time, right size, right chemical form to have desired effect
  - Oxides, metals, gases, etc



90 100
130 140
7%
5%
3%
1%
6%
4%
2%
Sr Zr
Tc
U-233
Pu-239
Cs
Cs
65%U
35%Pu
U-235
129I
Pd
Sn
Sm
80 90 110 120 150 160


Nuclides and Isotopes
Chart of the Nuclides

Ba130 Ba131 Ba132 Ba133 Ba134 Ba135 Ba136 Ba137 Ba138 Ba139 Ba140 Ba141 Ba142 Ba143 Ba144
Cs129 Cs130 Cs131 Cs132 Cs133 Cs134 Cs135 Cs136 Cs137 Cs138 Cs139 Cs140 Cs141 Cs142 Cs143
Xe128 Xe129 Xe130 Xe131 Xe132 Xe133 Xe134 Xe135 Xe136 Xe137 Xe138 Xe139 Xe140 Xe141 Xe142
I127 I128 I129 I130 I131 I132 I133 I134 I135 I136 I137 I138 I139 I140 I141
Te126 Te127 Te128 Te129 Te130 Te131 Te132 Te133 Te134 Te135 Te136 Te137 Te138 Te139 Te140
Sb125 Sb126 Sb127 Sb128 Sb129 Sb130 Sb131 Sb132 Sb133 Sb134 Sb135 Sb136 Sb137 Sb138 Sb139
Sn124 Sn125 Sn126 Sn127 Sn128 Sn129 Sn130 Sn131 Sn132 Sn133 Sn134 Sn135 Sn136 Sn137
In122 In123 In124 In125 In126 In127 In128 In129 In130 In131 In132 In133 In134 In135
Cd121 Cd122 Cd123 Cd124 Cd125 Cd126 Cd127 Cd128 Cd129 Cd130 Cd131 Cd132
Ag120 Ag121 Ag122 Ag123 Ag124 Ag125 Ag126 Ag127 Ag128 Ag129
Pd119 Pd120 Pd121 Pd122 Pd123 Pd124
Rh118 Rh119 Rh120 Rh121 Rh122
88
86
84
82
80
78

SO, WHERE ARE WE…

- 500 yds horizontal distance – low exposure from burst 10m underground
- Low exposure from surface (assuming overburden)
- Assume widespread contamination at surface - radiation
- Assume widespread devastation at surface
- ? contaminated air infiltration
- Hopefully someone knows where we are (were)
  - Kinda busy with other issues
  - Time is available for us to survive

NCRP 161 TABLE

Factors like mouth breathing, respiratory issues, etc., actual particle size, and chemical composition complicate calculations.

Deterministic effect is an observable effect, not a risk-based (somatic) effect like cancer, and doesn't need to be fatal.

Time scale for given effect is 2-3 months post-exposure.

TABLE 3.12—*Estimates of the concentrations in air [MBq m^{-3} (μCi m^{-3})] of several radionuclides that would have to be inhaled for 10 min to achieve intakes sufficient to produce deterministic effects or give effective doses of 0.25 Sv (25 rem) (Section 16.7).*

Radionuclide[a]	Air Concentrations Required to Cause Deterministic Effects[b,c]	Air Concentrations Required to Result in an Intake of 1 CDG Leading to an Effective Dose of 0.25 Sv (25 rem)[c]
$^{90}SrCl_2$ (Type F)	2,600 (70,000) Bone-marrow depression	51 (1,400)
^{131}I (Vapor)	30 (800) Hypothyroidism	76 (2,100)
$^{137}CsCl$ (Type F)	8,000 (220,000) Bone-marrow depression	350 (9,500)
$^{144}CeO_2$ (Type S)	3,700 (100,000) Pneumonitis	52 (1,400)
$^{210}PoCl_2$ or $^{210}PoCl_4$ (Type M)	1,900 (51,000) Bone-marrow depression	0.67 (18)
$^{238}PuO_2$ (Type M)	40 (1,100) Pneumonitis	0.049 (1.3)
$^{239}PuO_2$ (Type S)	40 (1,100) Pneumonitis	0.18 (4.9)
$^{241}AmO_2$ (Type M)	40 (1,100) Pneumonitis	0.57 (1.5)

[a]The radionuclides shown here are used as examples to demonstrate the levels of airborne activity required to cause serious health concerns. Assumed a breathing rate of 1.2 m^3 h^{-1} of unfiltered air for an adult and a lognormal particle-size distribution with AMAD = 5 μm.

[b]Deterministic effects expressed within two to three months are given for the particular radionuclide.

[c]Calculations based on a breathing rate of 1.2 m^3 h^{-1} of unfiltered air by an adult, 5 μm AMAD particles, and a total deposition of 82 % (ICRP, 1994a).

ALL IS NOT LOST!

The plans for Operation Teapot, at the Nevada Proving grounds during 1955, included a series of Civil Effects Tests, one of which, Project 32.2, covered the exposure of packaged food products. As this project developed, it was expanded to cover representative commercially packaged beverages, such as soft drinks and beer, in glass bottles and metal cans.

Preliminary experimental results were obtained from lest layouts exposed to a detonation of approximately nominal yield. Extensive test layouts were subsequently exposed during Operation Cue, of 50 per cent greater than nominal yield, at varying distances from Ground Zero. These commercially packaged soft drinks and beer in glass bottles or metal cans survived the blast overpressures even as close as 1270 ft from Ground Zero, and at more remote distances, with most failures being caused by flying missiles, crushing by surrounding structures, or dislodgment from shelves.

Induced radioactivity, subsequently measured on representative samples, was not great in either sort drinks or beer, even at the forward positions, and these beverages could be used as potable water sources for immediate emergency purposes as soon as the storage area is safe to enter alter a nuclear explosion.

Although containers showed some induced radioactivity, none of this activity was transferred to the contents. Some flavor change was found in the beverages by taste panels, more in beer than in soft drinks, but was insufficient to detract from their potential usage as emergency supplies of potable water.

Half life was observed to be 12-15 hours – Na 24 is 15 hours

RADIATION DAMAGE

- Ionizing radiation ionizes materials
- Free radicals produced
  - Oxygen and water easily involved in free radical formation
    - Form peroxides
  - Free radical scavengers are radioprotective
    - Must be there at time of formation
  - May inactivate cellular mechanisms, interact with DNA or RNA directly
    - Cells most sensitive during mitosis

RADIOSENSITIVITY OF NORMAL CELLS

- ***Very high:*** Lymphocytes, Immature hematopoietic cells, Intestinal epithelium, Spermatogonia, Ovarian follicular cells
- ***High:*** Urinary bladder epithelium, Esophageal epithelium, Gastric mucosa, Mucous membranes, Epidermal epithelium, Epithelium of optic lens
- ***Intermediate:*** Endothelium, Growing bone and cartilage, Fibroblasts, Glial cells, Glandular epithelium of breast, Pulmonary epithelium, Renal epithelium, Hepatic epithelium, Pancreatic epithelium, Thyroid epithelium, Adrenal epithelium
- ***Low:*** Mature hematopoietic cells, Muscle cells, Mature connective tissues, Mature bone and cartilage, Ganglion cells

From *Medical Effects of Ionizing Radiation* , Mettler, F. A. and Moseley , R. D., Eds., Grune & Straiton, New York, 1985

HIGH RADIATION EXPOSURE

Shielding 10% of active bone marrow may result in no deaths in LD50 range

Susceptibility varies with age, concurrent medical issues

With appropriate supportive therapy individuals may survive whole body exposures > 1200 R

In animals LD50 values are ~20% higher for unilateral vs bilateral exposure, and dorsal is about 2/3 of the ventral value

For children values are probably factor of 2 lower.

Highest value probably about puberty, and decreases with age

From *Medical Effects of Ionizing Radiation* , Mettler, F. A. and Moseley , R. D., Eds., Grune & Straiton, New York, 1985

TABLE I

Expected Temporal Distribution of Symptoms Following Whole-Body Irradiation

Midline tissue dose	Symptom	Percentage	Time postexposure
0.5—1.0 Gy (50—100 rads)	Anorexia	15—50	3—18 h
	Nausea	5—30	3—20 h
	Vomiting	15—20	4—16 h
1—2 Gy (100—200 rads)	Anorexia	50—90	1—48 h
	Nausea	30—70	4—30 h
	Vomiting	20—50	6—24 h
	Fatigue	25—60	3—72 h[a]
	Weakness	25—50	3—48 h
	Bleeding (mild)	10	1—5 weeks
	Fever	10—60	2 d—5 weeks
	Infection	10—50	1—5 week
	Death	<5	5—6 week
2—3.5 Gy (200—350 rads)	Anorexia	90—100	1—48 h
	Nausea	70—90	1—48 h
	Vomiting	50—80	3—24 h
	Diarrhea	10	4—8 h
	Fatigue (moderate)	60—90	2 h—6 weeks
	Weakness (moderate)	50—80	2 h—6 weeks
	Bleeding	10—50	1—5 week
	Fever	10—80	1—5 week
	Infection	10—80	2—5 week
	Ulceration	30	3—5 week
	Death	5—50	4—6 week
3.5—5.5 Gy (350—550 rads)	Anorexia[b]	100	1—72 h
	Nausea[b]	90—100	1—72 h
	Vomiting[b]	80—100	3—24 h
	Diarrhea[b]	10	3—8 h
	Fatigue	90—100	1 h—6 weeks
	Weakness	90—100	1 h—6 weeks
	Headache	50	4—24 h
	Bleeding	50—100	6 d—6 weeks
	Fever and infection	80—100	6 d—6 weeks
	Death	50—99	3.5—6 weeks
5.5—7.5 Gy (550—750 rads)	Anorexia	100	1—72 h
	Nausea	100	1—72 h
	Vomiting	100	1—48 h
	Diarrhea	10	4—6 h
	Fatigue and weakness (severe)		1 h—2 weeks
	Dizziness and disorientation	100	4—48 h
	Headache	80	4—30 h
	Bleeding, fever, infection, hypotension	100	10—14 d
	Death	100	2—3 weeks

[a] Possibly up to 6 wk.
[b] Symptom occurs in 60—100% of those exposed at 3—6 weeks.

FOUR PHASES OF ACUTE RADIATION SYNDROME
#1 - PRODROMAL

- ~1-6 (or 48) hours post exposure
  - Transitory symptoms, proportional to dose
  - Abnormalities in autonomic nervous system responsible for early GI symptoms
    - Anorexia , nausea, vomiting, diarrhea, intestinal cramps, salivation, and dehydration
  - Can be prevented by shielding the abdomen, unless large doses to the head
- 200-400 R (2-4 Sv) – N/V often in 1st two hours, mild headache, no diarrhea, temp increases in 10-80% in 1-3 hours
- 400-800 (4-8 Sv) R Vomiting is constant in < 1 hour, severe headache, diarrhea in 10 % in 1-8 hours. Fever is moderate to high in ~ 1 hr. Xerostomia & parotiditis frequent.
- >800 R (8 Sv) Vomiting in minutes, LOC may be affected, Diarrhea in minutes to 1 hour, temp up to 41 C

FOUR PHASES OF ACUTE RADIATION SYNDROME #2 - LATENT

- Extends to 20-30 days
  - Reflects time from rad-induced initial cell lesions and clinical expression
    - Dependent on cell turnover
  - Days 20-30 correspond to nadir of leukocyte and platelet counts
  - < 400 R (4Sv), prodromal symptoms subside in 48 hours, and Pt is asymptomatic for 1-3 weeks, then hematologic abnormalities become obvious.
  - 600-800 R (6-8 Sv), latent period is <7 day (then sepsis and GI)
  - > 1500 R (15 Sv)– hours to vascular issues
- Hematopoetic growth factors can be administered
  - G-CSF - granulocyte colony-stimulating factor – used in oncology – use ASAP post exposure. Not a single dose administration.
  - GM-CSF granulocyte macrophage-colony-stimulating factor – more adverse effects, mainly capillary leakage
- Stem Cells (?)

The Medical Basis for Radiation-Accident Preparedness, R.Ricks, et.al. Eds. New York, 2002

FOUR PHASES OF ACUTE RADIATION SYNDROME
3 - MANIFEST ILLNESS

- Hematopoietic
  - >200 R (2 Sv), up to 700 R (7 Sv)
  - Damage to bone marrow stem cells and lymphatic organs
  - Rapid reduction in lymphocytes (w/I 48 hours), may be transient rise in granulocytes and platelets, but then a decrease, with nadir in ~30 days
- Gastrointestinal
  - When trunk exposure >700 R (7 Sv), latent period 1-4 days. <1200 R (12 Sv) regeneration of bowel epithelium is possible. Otherwise loss of mucosal crypt cells. Mortal in 3-14 days.
- Cardiovascular
  - Debates about cardiovascular or neurovascular syndrome
- Central Nervous System
  - Initial nerve stimulation, then cerebral edema ~ 10 kR (100 Sv)
  - Mortality in 36-48 hours

FOUR PHASES OF ACUTE RADIATION SYNDROME # 4 - RECOVERY… OR NOT

- Mucosal lesions on tonsils, pharynx, nasal passages, and tongue.
- Edema may extend to larynx.
- 500-1000 R (5-10 Sv) hyperemia of oral and nasal cavities. Day 4-5 edema of soft palate and posterior pharynx. Followed by bleeding, ulceration, and necrosis. Healing is slow, but improved with antibiotics.
- Oropharyngeal changes seen in Chernobyl Pts, in days 8-25 – desquamation and edema of tongue and cheeks, gum tenderness.
- Pulmonary changes can occur – Chernobyl – respiratory insufficiency and pneumonitis, autopsies revealed interstitial edema (14-30 days to death), but no destruction of tracheal or bronchial epithelium .

RADIONUCLIDE CONTAMINATION

- Chelating (from *chele* Latin/Greek for claw)
  - Binds to metal ions, sequesters, and is excreted
  - Ca-DTPA is ~ 10x more effective for initial chelation of TRUs w/in 24 hours
  - Zn-DTPA is less toxic, and is as effective as Ca-DTPA for long-term
  - Plutonium, americium, curium, and californium. Debates about Np, Th, and U
- Blocking -Iodine
- Isotopic dilution - Tritium
- Alter its chemistry – NaHCO3 for uranium carbonates in renal tubules
- Binding – Prussian blue for cesium and thallium
- Procedures – Emesis, gastric lavage, cathartics, bronchoalveolar lavage

WORKING A RAD CASUALTY

- Contamination
  - Their contamination is unlikely to affect caregiver
    - It's been a while from exposure to treatment
    - Your exposure time will probably be short in comparison to theirs
    - Otherwise it may not be advised – triage
- Fragment
  - Caregiver shielding
- **IT DEPENDS**
- 10 R (100 mSv)/hr source in the palm
- Heavy contamination/moderate/deconned?

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